

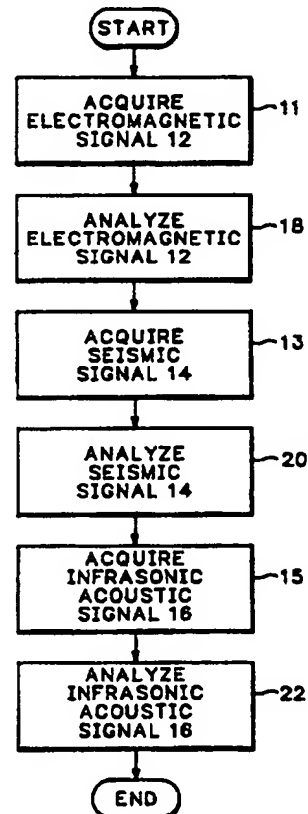
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(54) Title: METHOD FOR FORECASTING AN EARTHQUAKE FROM PRECURSOR SIGNALS**(57) Abstract**

A method for forecasting an earthquake from precursor signals by employing characteristic first electromagnetic signals (12), second, seismically induced electromagnetic signals (14), seismically induced mechanical signals, and infrasonic acoustic signals (16) which have been observed to precede an earthquake. From a first electromagnetic signal, a magnitude, depth beneath the surface of the earth, distance, direction, latitude, longitude, and first and second forecasts of the time of occurrence of the impending earthquake may be derived (18). From a second, seismically induced electromagnetic signal and the mechanical signal, third and fourth forecasts of the time of occurrence of an impending earthquake determined from the analysis above, a magnitude, depth beneath the surface of the earth and fourth and fifth forecasts of the time of occurrence of the impending earthquake may be derived (22). The forecasts of time available from the above analyses range from up to five weeks to substantially within one hour in advance of the earthquake.



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5 METHOD FOR FORECASTING AN EARTHQUAKE
 FROM PRECURSOR SIGNALS

Background of the Invention

 This invention relates to forecasting the magnitude,
location, depth and timing of an earthquake by the acquisition
10 tion and interpretation of extremely low frequency acoustic,
seismic and electromagnetic signals which precede it.

 The importance of an accurate method of forecast is
manifest--the annual number of deaths due to earthquake has
averaged about 17,000 throughout this century. Forecasting
15 may allow people to take life-saving precautionary measures.
But, Cinna Lomnitz, in his 1994 book, "Fundamentals of
Earthquake Prediction," opines that "earthquake prediction .
. . in the sense of forecasting the date, location, and
magnitude of an earthquake" is simply not yet feasible
20 today. Earthquake forecasting to date has been largely
unsuccessful, apparently because the theory of plate
tectonics is incomplete, and because empirical relationships
between measurable phenomena and subsequent earthquake
activity that may reliably forecast that activity have not
25 been discovered.

 Using the well known "hypothesis of characteristic
earthquakes," earthquakes along the San Andreas Fault in
California have been forecast statistically, by noting the
time periods between previous earthquakes and assuming a
30 characteristic time and location for the build-up and
release of strain energy. The 1989 Loma Prieta earthquake
was claimed to have been, to some extent, "predicted" by
this means, however to many geologists, the actual location
of and mechanism for its occurrence undermined the determin-
35 istic hypothesis supporting the method. In addition, even
if earthquake processes are deterministic, statistical
uncertainty remains in amounts sounding the death knell for
forecasting that would allow for the taking of temporary
precautionary measures, e.g., evacuation. See, Cinna
40 Lomnitz, Fundamentals of Earthquake Prediction, 36-41,
(1994).

5 Another method of forecasting is to measure accumulated
ground strain as an indication of impending energy release
due to the inexorable sliding or subductive motion of the
underlying plates. In order for this indicator to give more
10 than a gross estimate of time, location, or even magnitude
of an eventual earthquake, many details about the physics of
the plates and the convective mantle processes which drive
them, as well as the local physical properties of the crust,
would need to be better known. See, e.g., Ibid. at 180-86.

 Another method of forecasting is to simply map the
15 locations and energies of past earthquakes to determine a
probability of future occurrence. An obvious difficulty
with this method is that it neglects completely the time
variable. Further, such a seismicity map of California made
six years in advance of two very damaging earthquakes in
20 Parkfield and San Fernando showed for those locations
saddlepoints of seismic energy, implying, with devastating
inaccuracy, that these were two of the least hazardous
locations along the San Andreas Fault. Ibid. at 105.

 Animal behavior, especially that of migrating or
25 swarming animals such as birds, bees and fish, has long been
thought to be a precursor to earthquake activity. However,
attempts to interpret and even to describe the precursive
behavior unambiguously, have been frustrating. A funda-
mental problem is that the range of animal behavior can be
30 quite broad, and specific behavior with respect to
earthquake activity, which is a relatively rare occurrence
in the life of one animal, is difficult to demonstrate.

 After the 1989 Loma Prieta earthquake, it was
discovered that electromagnetic radiative signals in the
35 frequency range of .01 Hz to .02 Hz increased dramatically
prior thereto, using an instrument that had been installed
just four months prior to the quake. No subsequent bursts
have been recorded, suggesting that the bursts may have been
precursors, but the evidence is considered by scientists to
40 be inconclusive, and no reliable method of earthquake
forecasting relying on these signals has previously been
determined. Ibid. at 138.

5 Haroun Tazieff, in his 1989 book, "Earthquake
Prediction," discusses a method of forecasting known in the
art as the "VAN method," developed by three Greek scientists
whose initials form the acronym. The method consists of
continuously recording telluric currents using a network of
10 monitoring stations which cover a particular region. These
currents move in sheets of electricity, in the soil, close
to the surface of the earth. By using two buried
electrodes, one oriented north-south and the other east-
west, a station is believed to acquire a SES (seismic
15 electrical signal) that "always seems to precede an
earthquake." See, Haroun Tazieff, Earthquake Prediction, 67
(1989). The intensity of the signal is thought to be
proportional to the predicted magnitude of the earthquake,
and inversely proportional to its distance from the station.
20 The SES signal is believed to manifest as a sudden
deviation, either negative or positive, in the otherwise
relatively stable value of telluric current. These
deviations are on the order of millivolts, and are known to
be confounded by noise for less energetic or more distant
25 quakes. Because, by this method, only the distance to the
forecasted earthquake may be determined, at least three
stations, separated by appropriate distances, are necessary
to triangulate the location of a forecasted earthquake. An
exception results from a station's having received an SES
30 from a particular area, which is thought to calibrate that
station to earthquakes from that region, so that only one
station is thought to be necessary to monitor activity at
that location.

There are many physical measurements that could be made
35 upon the earth with a hope of correlating to impending
seismic activity. For example, changes in deep water
levels, sound wave velocity, emissions of gas, electrical
resistivity and magnetic field have all been proposed as
potentially useful indicators. But all of these attempts to
40 date have failed to provide accurate, repeatable forecasting
at specific locations and times. The VAN method is thought
by its proponents to provide accurate, repeatable

5 forecasting; however, it generally requires the use of at
least three monitoring stations, widely dispersed enough to
accurately triangulate, yet close enough to the site to
receive signals distinguishable from noise. Further, the
method is not thought to give a precise forecast of time,
10 its resolution being no better than about ten days.
Finally, it is reasonable to suspect that the method, since
it has been known in the art for more than five years and
earthquake forecasting is still not available to the public,
is not as robust as has been thought. Since there can be no
15 doubt of sufficient motive to employ immediately any reason-
ably cost efficient and workable technique to minimize the
devastating effects of earthquakes, the absence of
widespread use of this method renders its capabilities
doubtful.

20 Accordingly, there is a need for a novel method for
reliably, precisely and cost efficiently forecasting seismic
activity, particular serious seismic activity that may
result in injury or death.

Summary of the Invention

25 The present invention provides a method for forecasting
an earthquake from precursor signals which solves the afore-
mentioned problems and meets the aforementioned need by
employing characteristic first electromagnetic, seismically
induced second electromagnetic, seismically induced
30 mechanical, and infrasonic acoustic signals which have been
observed to precede an earthquake. The method for fore-
casting an earthquake according to the present invention
comprises measuring and interpreting four kinds of
precursive signals: infrasonic first electromagnetic signals
35 in the frequency range of zero to 10 Hz, seismically induced
second electromagnetic signals in the frequency range zero
to one Hz, seismically induced mechanical signals in the

5 same frequency range, and infrasonic acoustic waves in the frequency range of zero to 10 Hz travelling in the atmosphere.

Naturally occurring first electromagnetic signals in the range of zero to 10 Hz are found normally to exhibit a relatively flat baseline which includes a characteristic noise. However, distinctive first electromagnetic signals indicative of impending earthquake activity are received up to five weeks in advance of the earthquake. These signals arrive serially in time, each signal exhibiting a characteristic fast transition (either positive or negative) from the baseline, followed by a first peak and a second peak, for quakes that are sufficiently distant from the location of signal receipt, within a few seconds, followed further by a substantially exponential decay toward a baseline, and followed still further by a steadily increasing variation from the baseline referred to herein as ringing. The time of first receipt of the signals provides a first time forecast of the earthquake. The time of cessation of the signals provides a second time forecast of the earthquake. The time between the first peak and the second peak (when available) is relatable to the distance to an impending earthquake, and the time from the first transition of the signal to its substantial decay is relatable to the depth of the impending earthquake. The amplitude of the signal is relatable to the magnitude of the impending earthquake. The ringing is observed to increase over time and, when Fourier or otherwise spectrally transformed to reveal frequency content, reveals a pronounced spectral peak which is observed over time to grow steadily in amplitude, centered at a frequency which is relatable to the latitude of the impending earthquake, and having a maximum amplitude which is relatable to the magnitude of the impending earthquake. The ringing, when analyzed for phase content provides a phase fluctuation, at the center frequency of the spectral peak, which is relatable to the longitude of the impending earthquake.

5 A substantial increase in a second, seismically induced
electromagnetic signal, received from an electromagnetic
transducer and representative of naturally occurring seismic
motion, sensed at the same site, that is either substan-
tially coincident with or follows the first electromagnetic
10 signals within approximately three weeks, increases the
probability that the first electromagnetic signals correlate
to an earthquake that will actually materialize rather than
be dissipated by alternative modes of energy release.
Further, the time of first receipt of the seismically
15 induced second electromagnetic signal provides a third
forecast of the time of the earthquake, and the time of
cessation of the signal provides a fourth forecast of the
time of the earthquake.

 The same information is available from a transducer,
20 buried in the earth substantially 500 miles or less for a
transducer having 10V/g, from the site of the impending
earthquake, adapted to convert mechanical motion to
electrical signals, which produces an electrical signal in
response to a seismically induced mechanical signal, but at
25 an increased resolution.

 Infrasonic acoustic waves measured at the site of the
impending earthquake located by analysis of the
electromagnetic signals provide a fifth and sixth forecast
of the time of the earthquake.

30 Therefore, it is a principle object of the present
invention to provide a novel and improved method for
forecasting of an earthquake.

 It is a further object of the present invention to
provide such a method that is reliable, precise and cost-
35 efficient.

 It is still a further object of the present invention
to provide such a method that minimizes the number of
continuous monitoring stations required.

40 It is another object of the present invention to
provide such a method to forecast an impending earthquake by
sensing a precursive electromagnetic signal.

5 It is yet another object of the present invention to provide such a method to forecast an impending earthquake by sensing a precursive seismic signal.

 It is still another object of the present invention to provide such a method to forecast an impending earthquake by
10 sensing a precursive atmospheric infrasonic acoustic signal.

 It is another object of the present invention to provide such a method which forecasts the magnitude of an impending earthquake.

 It is yet another object of the present invention to
15 provide such a method which forecasts the distance to the site of an impending earthquake.

 It is still another object of the present invention to provide such a method which forecasts the depth of an impending earthquake.

20 It is a further object of the present invention to provide such a method which forecasts the latitude of the site of an impending earthquake.

 It is yet a further object of the present invention to provide such a method which forecasts the longitude of the
25 site of an impending earthquake.

 It is still a further object of the present invention to provide such a method which forecasts the time of surface occurrence of an impending earthquake.

 The foregoing and other objects, features and
30 advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

Brief Description of the Drawings

35 Figure 1 is a flow diagram showing an overview of a method for determining the location, magnitude and timing of an impending earthquake according to the present invention.

 Figure 2 is an exemplary representation of the amplitude in millivolts of a characteristic electromagnetic
40 signal precursive of an earthquake measured with respect to time according to the present invention.

5 Figure 3 is a representation of the amplitude in microvolts of the frequency spectrum of a first portion of the electromagnetic signal of Figure 1, according to the present invention

10 Figure 4 is a representation of the amplitude in microvolts of the frequency spectrum of a second portion of the electromagnetic signal of Figure 1, according to the present invention.

15 Figure 5 is an exemplary representation of the phase of the second portion of the electromagnetic signal of Figure 4 as a function of frequency, according to the present invention.

20 Figure 6 is a flow diagram of a preferred embodiment of a method according to the present invention, to verify the likelihood of an impending earthquake and to provide a first time forecast of the impending earthquake.

 Figure 7 is an exemplary representation of the development, over time, of the magnitude of a seismic signal, utilized in conjunction with the method of Figure 6.

25 Figure 8 is a flow diagram of a preferred embodiment of a method according to the present invention, to provide a second time forecast of an impending earthquake.

 Figure 9 is an exemplary representation of the development, over time, of the magnitude of an infrasonic signal, utilized in the method of Figure 8.

30 Detailed Description of a Preferred Embodiment

 Referring to Figure 1, a method 10 for forecasting an impending earthquake according to the present invention comprises acquiring a first electromagnetic signal 12 (Figure 2), at step 11, a pair of seismic signals 14 (Figure 7), at step 13, and an infrasonic acoustic atmospheric signal 16 (Figure 9), at 15. The seismic signals 14 include a second, seismically induced electromagnetic signal portion and a seismically induced mechanical signal portion. Both portions carry substantially the same information and will be treated alike for purposes of analysis herein. Each acquisition step 12, 14 and 16 is followed by a step 18, 20

5 and 22, respectively, wherein the signal received in the
preceding step is analyzed to provide information about the
impending earthquake. The impending earthquake will be
defined herein as an anticipated shaking of the ground at
the surface of the earth in response to underlying seismic
10 activity which produces these precursive signals. The
signals 12, 14 and 16 are all preferably acquired by
suitable receiving apparatus (not shown). Suitable
receiving apparatus for the signal 12 include that described
in Farnsworth, et. al., patent application No.
15 PCT/US94/02630, hereinafter incorporated by reference in its
entirety, where adapted to eliminate through filtration
frequency components of the signal 12 above substantially 10
Hz. Suitable receiving apparatus for the signal 14 include
that described in Farnsworth, et. al., patent application
20 No. PCT/US94/02626, hereinafter incorporated by reference in
its entirety, for the seismically induced electromagnetic
signal portion of the signal 14, and a pair of horizontally
and vertically disposed accelerometers providing at least
ten volts/g, where "g" is the acceleration of gravity, such
25 as marketed by PCB Electronics of Depew, New York as model
No. 393B12, for the seismically induced mechanical signal
portion of the signal 14. Both sets of apparatus are
adapted to respond to frequency components of the signal 14
below substantially one Hz. Suitable receiving apparatus
30 for the signal 16 are adapted to receive signals in the
range of zero to 10 Hz, and preferably include a digital
signal analyzer and an infrasonic microphone having a
sensitivity of about 0.01 Pascals or better.

The first electromagnetic signal 12 is preferably
35 received from the electrical power grid and monitored
continuously; however, it may be obtained with other
suitable antennae and sampled between suitable time periods
without departing from the principles of the invention.

The first electromagnetic signal 12 is analyzed
40 according to step 18 to provide the location, magnitude and
a first and second time forecast of an impending earthquake.
The seismic signal 14 is determined according to step 20 to

5 verify the materialization of the impending earthquake and
to provide a third and fourth time forecast of the impending
earthquake. The infrasonic signal 16 is analyzed according
to step 22 to provide a fifth and sixth time forecast of the
impending earthquake, and may also be utilized to provide
10 estimated magnitude and depth of the impending earthquake.

Referring to Figure 2, the step 11 of acquiring the
first electromagnetic signal 12 includes locating a series
of characteristic pulses 24 (only one characteristic pulse
24 is shown in Figure 2). It has been found that the series
15 of characteristic pulses 24 are indicative of a likelihood
of an impending earthquake somewhere in the world. The
electromagnetic signal 12 is preferably acquired by a
digital signal analyzer which provides both time domain and
frequency domain information and is reported in the time
20 domain as a voltage amplitude 26, typically in millivolts,
and a time 28, typically in seconds, for resolving
beneficially the characteristic pulse 24. The pulse 24
includes a fast transition 30, a first peak 32, a second
peak 34, a decay 36 and a ringing 38.

25 The fast transition 30 is shown in Figure 2 as a rise
in amplitude, i.e. a positive transition, however it may be
a negative going change in amplitude, i.e. a negative
transition. Accordingly, for purposes herein, a reduction
in the absolute value of the amplitude is referred to as a
30 fall and an increase in the absolute value of the amplitude
is referred to as a rise. Whether a pulse 24 rises or falls
has been found to depend, at any given time, on the
hemisphere of the earth in which the impending earthquake
originates. Whether a pulse rises or falls determines
35 whether the decay 36 falls or rises respectively toward the
baseline.

The step 18 of analyzing the first electromagnetic
signal comprises determining a time 39 in seconds between
the first peak 32 and the second peak 34. It has been found
40 that the time 39 is dependent upon the distance to the
impending earthquake apparently due to dispersive broadening
of the pulse 24 that occurs during the propagation time of

5 the electromagnetic signal 12 within and along the earth.
When corrected for this broadening, the time 39 has been
found to be proportional to the distance, along the surface
of the earth, to the site of the impending earthquake.
Consequently, the distance along the surface of the earth to
10 the impending earthquake is determined by multiplying the
time 39 by an appropriate predetermined constant. This
constant has been found to vary between substantially 100
miles/second and 2400 miles/second, depending substantially
proportionally upon distance, with greater distances
15 associated with greater speeds, when the earthquake arises
within the United States and the antennae is the United
States power grid. Further, the second peak 34 may be
arbitrarily close in time to the first peak 32, for near
field earthquakes. Consequently, for filtering of the
20 electromagnetic signal of 10 Hz, earthquakes nearer to the
site of detection of the electromagnetic signal 12 than
substantially 10 to 240 miles, under the conditions
described above, will not be evidenced by a second peak 34,
and therefore no distance forecast is provided by the
25 aforescribed analysis.

The step 18 of analyzing the electromagnetic signal
further comprises determining a pulse width 43 between the
time of initiation 44 of the fast transition 30 (which for
purposes herein, is considered equal to the time of
30 initiation of the first peak 32), and the time of
termination 46 of a 90% decay of the decay 36. It has been
found that the time 46 is also dependent on the distance to
the impending earthquake, apparently due to dispersive
broadening of the pulse 24 that occurs during the
35 propagation time of the electromagnetic signal 12 within and
along the earth. When corrected for this broadening, the
pulse width 43 has been found to be proportional to the
depth, below the surface of the earth, of the impending
earthquake. Consequently, the depth of the impending
40 earthquake is forecasted by multiplying the pulse width 43
by a predetermined constant calculated from empirical data.

5 The step 18 still further comprises determining a
voltage amplitude 48 of the first peak 32. The voltage
amplitude 48 has been found to be proportional to the
magnitude of the impending earthquake. The amplitude is
dependent on, inter alia, the sensitivity of the monitoring
10 equipment and attenuation of the signal 12 by the antennae.
Consequently, the magnitude of the impending earthquake is
forecasted by multiplying the amplitude 48 by a
predetermined constant calculated from empirical data.

 A time of first initiation (not shown) of the first
15 electromagnetic signal 12 has been found to occur
substantially five weeks or less in advance of the
occurrence of the earthquake, providing a first time
forecast of the earthquake. The time of first initiation is
the first time at which the first electromagnetic signal 12
20 is discernible. A time of cessation (also not shown) of the
first electromagnetic signal has been found to occur
substantially one day in advance of the occurrence of the
earthquake, providing a second time forecast of the
earthquake. The time of cessation is the last time at which
25 the electromagnetic signal 12 is discernible. It has been
found that the electromagnetic signal 12 substantially
abruptly extinguishes itself at the time of cessation, as
compared to its rate of change following its initiation.

 Referring to Figures 2 and 3, the step 18 still further
30 comprises operating upon the electromagnetic signal 12
mathematically so that it is projected onto sinusoidal basis
functions, as in a Fourier transform, to provide a frequency
spectrum 50. This preferably is done using the
aforementioned digital signal analyzer. The frequency
35 spectrum 50 is reported as a voltage amplitude 52 and a
frequency 54. In a preferred embodiment, the voltage
amplitude 52 is reported in microvolts and the frequency 54
is reported in the range of zero to 10 Hz. The frequency
spectrum 50 comprises spectral peaks 56 defined by
40 frequencies 58 which have been found to be indicative of the
latitude of earthquake sites thus monitored. When operated
upon prior to the ringing 38, peaks 56 of the

5 electromagnetic signal 12, when roughly equal to one another in amplitude 52, are not indicative of an impending earthquake, consequently the peaks 56 are non-indicative peaks.

10 However, referring to Figures 2 and 4, when operating upon the electromagnetic signal 12 at the time during the ringing 38 in the manner described above, to provide a frequency spectrum 50, also as above, some of the spectral peaks 56 are found to increase in amplitude 52. When the peaks 56 increase substantially together, there is again no indication of an impending earthquake at the latitudes 15 corresponding to those frequencies 58, and consequently the peaks 56 remain non-indicative peaks. However, an indicative peak 60 will be noticed to increase much more than the non-indicative peaks 56. As the series of pulses 20 24 (Figure 1) become closer in time 28 (Figure 1), the indicative peak 60 will be seen to rise further above the non-indicative peaks 56. The frequency 62 about which an indicative peak 60 is centered has been found to be relatable to the latitude of the impending earthquake. The 25 latitude at the rotational poles of the earth has been found to correspond substantially to 7.8 Hz, while the latitude at the equator of the earth has been found to correspond substantially to zero Hz, the dependence of frequency on latitude therebetween varying sigmoidally. The latitude of 30 the impending earthquake is forecasted by relating the frequency 62 to a corresponding predetermined value of latitude. In a preferred embodiment, the latitude of the impending earthquake is forecasted by relating the frequency 62 to a predetermined value obtained from a look up table 35 based on empirical data collected by monitoring over a period of time the electromagnetic signals associated with many earthquakes. The look-up table is preferably encoded for use by a computer.

40 The step 18 still further comprises determining the magnitude 64 of the indicative peak 60. The magnitude of the impending earthquake has been found to be proportional to the transcendental constant "e" raised to the power of

5 the amplitude 64. Consequently, the magnitude of the
impending earthquake is forecasted by multiplying "e" raised
to the power of the amplitude 64 by a predetermined constant
calculated from empirical data. This method of forecasting
the magnitude of the impending earthquake, with respect to
10 the aforescribed alternative based upon analysis of the
pulse 24, is considered the preferred method.

Referring to Figure 5, the step 18 still further
comprises operating upon the electromagnetic signal 12 to
provide a phase versus frequency spectrum 65. The phase of
15 signal 12 corresponding to the frequency 62 of the
indicative peak 60 has been found to change with time. More
specifically, it has been found that a magnitude 67 (which
may be positive or negative) of the total phase fluctuation
is proportional to the longitudinal difference in the
20 location of the site of the impending earthquake and the
location of the acquisition of the electromagnetic signal
12. Consequently, the longitudinal difference is forecasted
by multiplying the magnitude 67 by a predetermined constant
calculated from empirical data.

25 A longitudinal direction may be determined by measuring
the phase difference between signals received by two
respective antennas displaced from one another, to
supplement the information provided by the phase versus
frequency spectrum 65.

30 Alternatively, a longitudinal direction may be
determined by employing a pair of directional antennae
disposed to provide a set of basis vectors in the horizontal
plane upon which a signal direction may be resolved, as will
readily be appreciated by one of ordinary skill in the art.

35 Alternatively, after having acquired sufficient data
over time, electromagnetic signals arising from known
locations may be seen in time, frequency or phase
representations to evidence a unique signature corresponding
to that location, allowing for the ascertainment of
40 earthquake location information without employing detailed
measurements and mathematical relationships between those
measurements and desired parameters.

5 Further, while the aforescribed method provides the
depth, latitude and longitude of, and distance to an
impending earthquake, and therefore is capable of providing
redundant surface location information even while only one
10 monitoring station is employed, less information may be
acquired and well known triangulation methods used to
determine the surface location of the impending earthquake
without departing from the principles of the invention.

It has been found that, in addition to the
aforescribed first electromagnetic signal 12, a second,
15 seismically induced electromagnetic signal portion of the
seismic signal 14, following in time the first
electromagnetic signal 12, provides further information
beneficial to the forecast of the earthquake. In addition,
a seismically induced mechanical signal portion of the
20 seismic signal 14 provides the same information as the
seismically induced electromagnetic signal portion, however
the seismically induced mechanical portion of the signal may
be discernibly received only when monitoring the signal
within substantially 500 miles, for a transducer providing
25 10V/g, from the site of the earthquake.

Referring, then, to Figures 6 and 7, either the second,
seismically induced electromagnetic signal portion of the
seismic signal 14 or the seismically induced mechanical
signal portion of the seismic signal 14 may be first
30 received at step 70.

A time of first initiation 72 of the seismic signal 14
is then determined at step 74 by noting the first time at
which the seismic signal 14 is discernible above noise 79
(Figure 7). A time 76 is also determined at step 78 for the
35 substantial rise of the indicative peak 60 (Figure 3). The
time 72 is then compared with the time 76 at step 80. If
the time 72 follows the time 76 by up to substantially three
weeks, then the seismic signal 14 is verification of the
materialization of the impending earthquake at the latitude
40 determined from the frequency 62 of the indicative peak 60.

Further, the time 72 has been found to occur
substantially two weeks or less in advance of the occurrence

5 of the earthquake, providing a third time forecast of the
earthquake. Still further, a time of cessation (not shown)
of the seismic signal 14 been found to occur substantially
within one hour, i.e., a few minutes up to an hour in
advance of the occurrence of the earthquake, providing a
10 fourth time forecast of the earthquake. The time of
cessation is the last time at which the seismic signal 14 is
discernible. It has been found that the seismic signal 14
substantially abruptly extinguishes itself at the time of
cessation, as compared to its rate of change following its
15 initiation at time 72.

Referring to Figure 7, the seismic signal 14 has been
found to exhibit a series of substantially sinusoidal
wavelets 75 that are characteristic of an impending
earthquake. The wavelets 75 associated with the impending
20 earthquake have been found to develop over time so that
their amplitude 77 is seen to grow steadily above the noise
79, as shown as an enveloping pattern 81 in Figure 7. This
pattern may collapse at any time, by the amplitude 77 of
subsequently received wavelets 75 decreasing to
25 substantially zero, indicating that the impending earthquake
will not materialize at the surface due to an alternative
mode of energy release. However, a pattern 81 that persists
at a sustained amplitude 83 over a sufficient period of
time, found to be substantially one to two hours, followed
30 by a sudden substantially complete cessation of amplitude
83, has been found indicative that the earthquake will
materialize substantially within one hour, providing a short
time forecast of the impending earthquake. The mechanically
coupled signals 19 are considered to provide better
35 resolution, and therefore to provide better forecasting
information, than the electromagnetically coupled signals
17.

Referring to Figures 8 and 9, an impending earthquake
site is determined at step 82 by analysis of the
40 electromagnetic signals 12 as described above. Infrasonic
acoustic signals 16 propagating in the atmosphere are then
monitored at step 84 with suitable apparatus as described

5 above. A time of first receipt 86 of the infrasonic
acoustic signals 16 is then determined at step 88, by noting
the time at which the infrasonic acoustic signals 16 begin
to exhibit a series of characteristic pulses 85 (Figure 9).
The characteristic pulses 85 have been found to include
10 features similar to those described for the electromagnetic
signals 12 but without a second peak 34 (Figure 2) because
the monitoring site will not be sufficiently distant from
the earthquake as has been discussed above. It has been
found that the time 86 of the first receipt of the
15 characteristic pulses 85 indicates that the impending
earthquake will follow in from one to three days, providing
a fifth forecast of the time of occurrence of the earthquake
at step 90.

It has also been found that infrasonic signals 16, over
20 a relatively short period of time, change from having
frequencies in a range of zero to 10 Hz to having
frequencies in the range of 20 Hz, where they will not be
excluded by a low pass filter of the monitoring apparatus.
Consequently, the infrasonic signals 16 will be seen to
25 cease at a characteristic time of cessae of cessation 88, and it has
been found that from this time an impending earthquake is
due within eight hours plus or minus one-half hour,
providing a sixth forecast of the time of occurrence of the
earthquake at step 94.

30 Further, because the characteristic pulses 85 of the
infrasonic signals 16 include features similar to the
characteristic pulses 24 of the electromagnetic signals 12
(Figure 2), information regarding magnitude, latitude,
longitude and depth of the impending earthquake is
35 ascertainable from these signals as well in the manner
described for the electromagnetic signals 12, however in a
preferred embodiment, in which the infrasonic signals are
measured at or near the site of the impending earthquake,
the latitude and longitude information contained therein is
40 not presently considered useful.

It is to be recognized that, while a specific method
has been described as the preferred embodiment of the

5 invention, other methods employing the principles of the
invention could be utilized without departing therefrom. It
is also to be recognized that, while these steps may be
performed manually, they are preferably carried out by a
digital processor appropriately programmed to identify the
10 pertinent points on the signal
waveforms and make the aforescribed computations.

The terms and expressions which have been employed in
the foregoing specification are used therein as terms of
description and not of limitation, and there is no intention
15 of the use of such terms and expressions of excluding
equivalents of the features shown and described or portions
thereof, it being recognized that the scope of the invention
is defined and limited only by the claims which follow.

5 I claim:

1. A method for forecasting an earthquake, comprising:

receiving a naturally occurring electromagnetic signal
at a known location on the earth;

10 determining whether, over a selected time interval, the
amplitude of said electromagnetic signal changes
more than a threshold amount, as a precursory
indication of an earthquake;

15 where said amplitude changes by an amount greater than
said threshold and thereafter decays, determining
the maximum value of said amplitude; and

multiplying said maximum value by a predetermined value
to determine the magnitude of said earthquake.

2. A method for forecasting an earthquake, comprising:

20 receiving a naturally occurring electromagnetic signal
at a known location on the earth;

determining whether, over a selected time interval, the
amplitude of said electromagnetic signal changes
more than a threshold amount, as a precursory
indication of an earthquake;

25 where said amplitude changes by an amount greater than
said threshold amount and thereafter decays,
identifying the time of occurrence of a resultant
first peak of said amplitude; and

30 where said amplitude thereafter falls and rises again a
predetermined amount, identifying the time of
occurrence of the resultant second peak of said
amplitude;

5 determining the time between said first peak and said
 second peak; and

 multiplying said time between said first peak and said
 second peak by a predetermined value to determine
 the distance over the surface of the earth from
10 said known location to said earthquake.

3. A method for forecasting an earthquake, comprising:

 receiving a naturally occurring electromagnetic signal
 at a known location on the earth;

 determining whether, over a selected time interval, the
15 amplitude of said electromagnetic signal changes
 more than a threshold amount, as a precursory
 indication of an earthquake;

 where said amplitude changes by an amount greater than
 said threshold amount and thereafter decays,
20 identifying the time of initiation of a resultant
 first peak of said amplitude;

 where said amplitude thereafter decays by a
 predetermined amount, identifying the time of
 termination of the decay;

25 subtracting the time of initiation from the time of
 termination to form a pulse width; and

 multiplying the pulse width by a predetermined value to
 determine the depth of said earthquake beneath the
 surface of the earth.

30 4. A method for forecasting an earthquake, comprising:

 receiving a naturally occurring electromagnetic signal
 at a known location on the earth;

5 transforming said electromagnetic signal over a
 selected time interval to provide a frequency
 spectrum;

 determining whether, during said selected time
 interval, the magnitude of a spectral peak is
10 greater than the magnitude of any other part of
 said spectrum by a predetermined amount;

 identifying the center frequency of said spectral peak,
 if determined; and

 determining the latitude of said earthquake based upon
15 a relationship to the center frequency.

5. The method of claim 4, wherein transforming said
electromagnetic signal is by a Fourier transform.

6. The method of claim 4, wherein determining said
latitude is by finding from a look-up table the latitude
20 corresponding to said center frequency.

7. A method for forecasting an earthquake, comprising:

 receiving a naturally occurring electromagnetic signal
 at a known location on the earth;

25 transforming said electromagnetic signal over a
 selected time interval to provide a frequency
 spectrum;

 determining whether, during said selected time
 interval, the magnitude of a spectral peak is
 greater than the magnitude of any other part of
30 said spectrum by a predetermined amount;

 identifying the center frequency of said spectral peak,
 if determined; and

5

multiplying said magnitude by a predetermined value, to determine the magnitude of said earthquake.

8. A method for forecasting an earthquake, comprising:

10

receiving a naturally occurring electromagnetic signal at a known location on the earth;

transforming said electromagnetic signal over a selected time interval to provide a frequency spectrum;

15

determining whether, during said selected time interval, the magnitude of a spectral peak is greater than the magnitude of any other part of said spectrum by a predetermined amount;

identifying the center frequency of said spectral peak, if determined;

20

transforming said electromagnetic signal over a selected time interval to provide a phase-frequency relationship;

determining the amount of a phase fluctuation associated with the center frequency; and

25

multiplying the amount of said phase fluctuation by a predetermined value to determine the longitude of said earthquake.

9. A method for forecasting an earthquake, comprising:

30

receiving a naturally occurring electromagnetic signal at a known location on the earth from a first antenna;

5 determining whether, over a selected time interval, the
 amplitude of said electromagnetic signal changes
 more than a threshold amount, as a precursory
 indication of an earthquake;

 receiving said naturally occurring electromagnetic
10 signal from a second antenna;

 determining a difference in the signals received from
 said first antenna and said second antenna; and

 determining from said difference the direction of said
 earthquake from said known location.

15 10. The method of claim 9, wherein said second antenna is
 disposed a predetermined distance from said first antenna,
 and wherein said difference is a phase difference in said
 signals.

 11. The method of claim 9, wherein said first antenna and
20 said second antenna are directional antennae, wherein said
 second antenna is disposed a predetermined orientation with
 respect to said first antenna, and wherein said difference
 is a relative amplitude of said signals.

 12. A method for forecasting an earthquake, comprising:

25 receiving a naturally occurring electromagnetic signal
 at a known location on the earth;

 determining whether, over a selected time interval, the
 amplitude of said electromagnetic signal changes
 more than a threshold amount, as a precursory
30 indication of an earthquake;

- 5 characterizing a signature of said electromagnetic
signal and correlating said signature with
empirical data to determine the location of said
earthquake.
13. A method for forecasting an earthquake, comprising:
- 10 receiving a naturally occurring electromagnetic signal
at a known location on the earth;
- determining a time of initiation of said
electromagnetic signal; and
- 15 determining a time of likely occurrence of said
earthquake from said time of initiation by adding
a predetermined period of time to said time of
initiation.
14. The method of claim 13, wherein said predetermined
20 period of time is substantially five weeks.
15. A method for forecasting an earthquake, comprising:
- receiving a naturally occurring electromagnetic signal
at a known location on the earth;
- determining a time of cessation of said electromagnetic
25 signal; and
- determining a time of likely occurrence of said
earthquake from said time of cessation, by adding
a predetermined period of time to said time of
cessation.
- 30 16. The method of claim 15, wherein said predetermined
period of time is substantially one day.
17. A method for forecasting an earthquake, comprising:

5 receiving a transducer signal induced by a naturally
 occurring seismic signal at a known location on
 the earth;

 determining whether said transducer signal exhibits a
 series of wavelets wherein said wavelets grow in
10 amplitude over a predetermined period of time, to
 provide a precursory indication of said
 earthquake; and

 determining a time of likely occurrence of said
 earthquake by identifying a time of initiation of
15 said wavelets.

18. The method of claim 17, wherein determining said time
of likely occurrence is by adding substantially two weeks to
said time of initiation.

19. The method of claim 17, wherein said transducer
20 transforms a first electrical signal to a second electrical
 signal.

20. The method of claim 17, wherein said transducer
transforms a mechanical signal to an electrical signal.

21. A method for forecasting an earthquake, comprising:

25 receiving a transducer signal induced by a naturally
 occurring seismic signal at a known location on
 the earth;

 determining whether said transducer signal exhibits a
 series of wavelets wherein said wavelets grow in
30 amplitude over a predetermined period of time, to
 provide a precursory indication of said
 earthquake; and

5 determining a time of likely occurrence of said
 earthquake by identifying a time of cessation of
 said wavelets.

22. The method of claim 21, wherein determining said time
of likely occurrence is by adding an amount of time
10 substantially within one hour to said time of cessation.

23. The method of claim 21, wherein said transducer
transforms a first electrical signal to a second electrical
signal.

24. The method of claim 21, wherein said transducer
15 transforms a mechanical signal to an electrical signal.

25. A method of forecasting an earthquake, comprising:

 receiving a transducer signal induced by a naturally
 occurring seismic signal at a known location on
 the earth;

20 determining whether said transducer signal exhibits a
 series of wavelets wherein said wavelets grow in
 amplitude over a predetermined period of time, to
 provide a precursory indication of said
 earthquake;

25 determining a time of likely occurrence of said
 earthquake by identifying a time of initiation of
 said wavelets;

 receiving a naturally occurring electromagnetic signal
 at a known location on the earth;

30 determining a time of initiation of said
 electromagnetic signal;

. 27

5 determining a time of likely occurrence of said
 earthquake from said time of initiation by adding
 a predetermined period of time to said time of
 initiation; and

 comparing said time of initiation of said
10 electromagnetic signal with said time of
 initiation of said wavelets wherein if said time
 of initiation of said wavelets wherein if said
 time of initiation of said electromagnetic signal
 precedes by substantially three weeks said time of
15 initiation of said wavelets, said comparing
 provides verification of the forecast of said
 earthquake.

26. A method for forecasting an earthquake, comprising:

 receiving a naturally occurring infrasonic acoustic
20 signal at a known location on the earth;

 determining a time of first receipt of said signal; and

 determining a time of likely occurrence of said
 earthquake by adding a predetermined value to said
 time of first receipt of said signal.

25 27. The method of claim 26, wherein said predetermined
 value is substantially one to three days.

28. A method for forecasting an earthquake, comprising:

 receiving a naturally occurring infrasonic acoustic
 signal at a known location on the earth;

30 determining a time of frequency shift of said signal to
 a substantially higher frequency; and

- 5 determining a time of likely occurrence of said
 earthquake by adding a predetermined value to said
 time of frequency shift.

29. The method of claim 28, wherein said predetermined
value is substantially eight hours.

- 10 30. A method for forecasting an earthquake, comprising:

 receiving a naturally occurring infrasonic acoustic
 signal at a known location on the earth;

 identifying the time of initiation of a resultant first
15 peak of said amplitude;

 where said amplitude thereafter decays by a
 predetermined amount, identifying the time of
 termination therefor;

 subtracting the time of initiation from the time of
20 termination to form a pulse width; and

 multiplying the pulse width by a predetermined value to
 determine the depth of said earthquake beneath the
 surface of the earth.

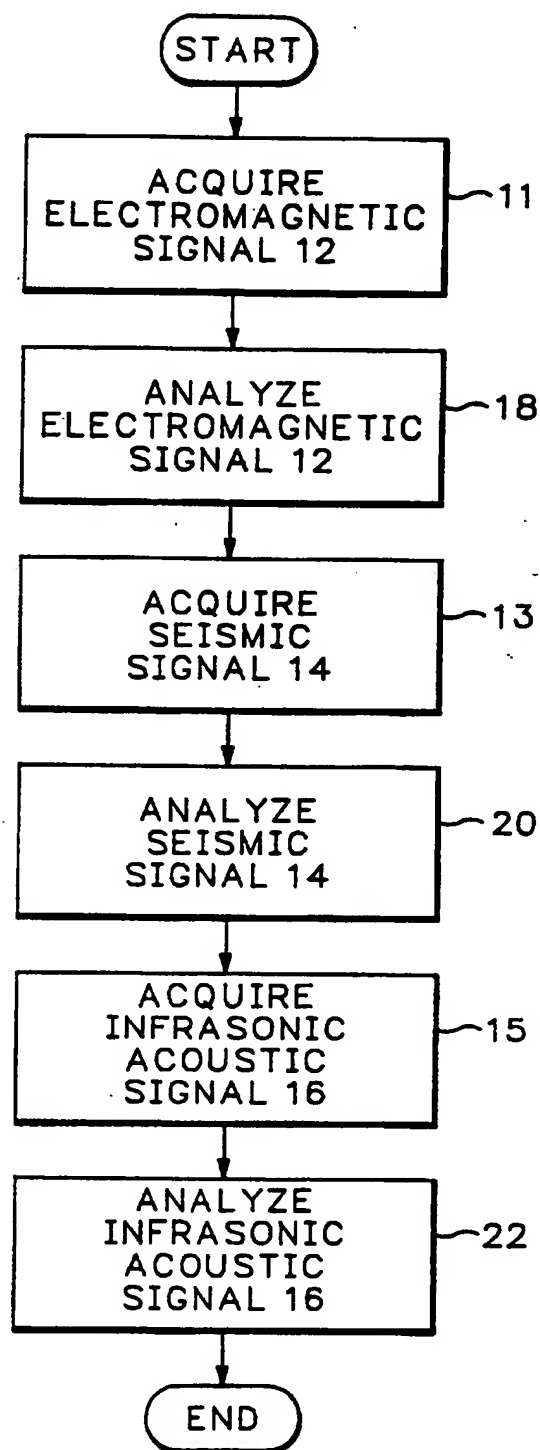
31. A method for forecasting an earthquake, comprising:

25 receiving a naturally occurring infrasonic acoustic
 signal at a known location on the earth;

 determining a maximum amplitude of said signal and

 multiplying said maximum amplitude by a predetermined
 value to determine the magnitude of said
30 earthquake.

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**Fig.1**

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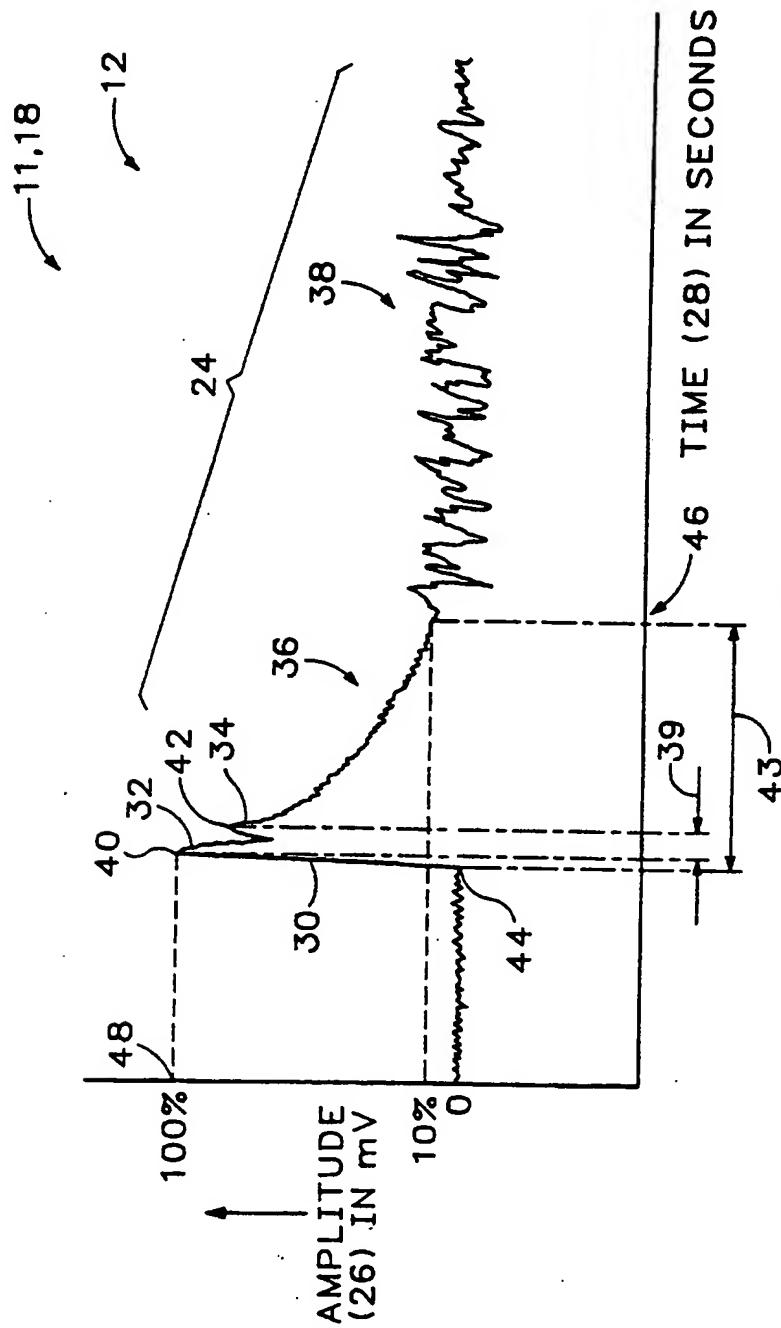


Fig.2

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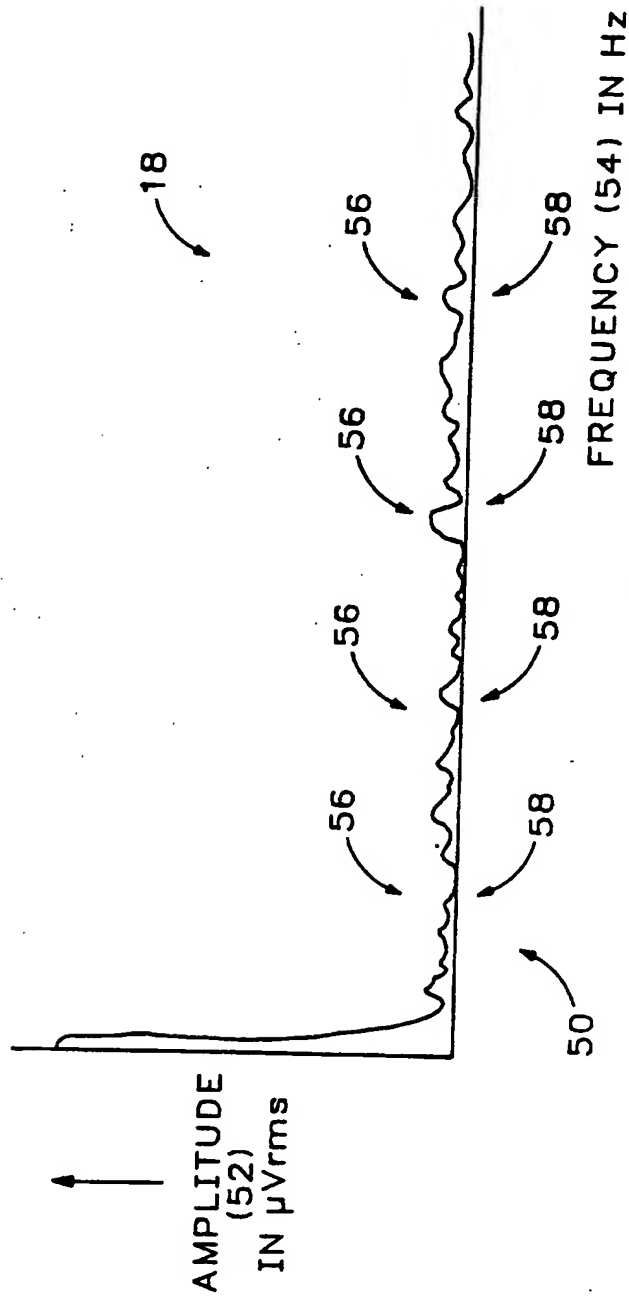


Fig.3

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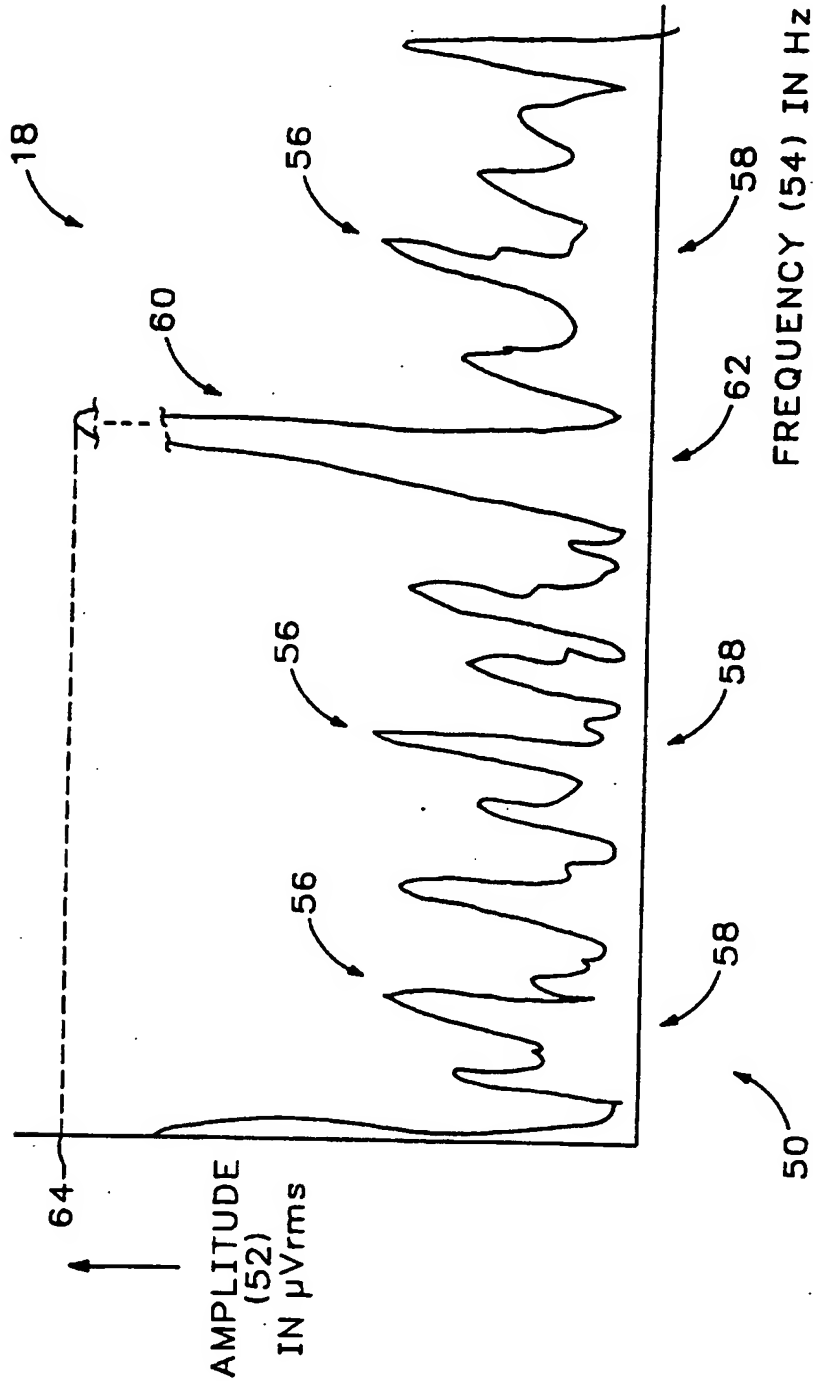


Fig.4

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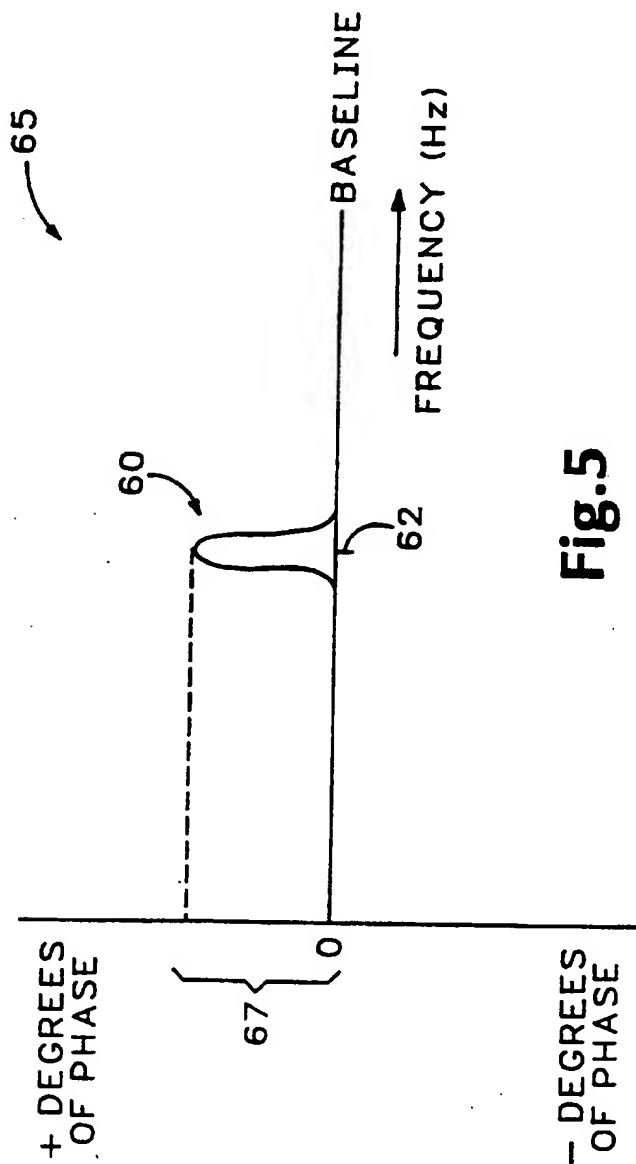


Fig.5

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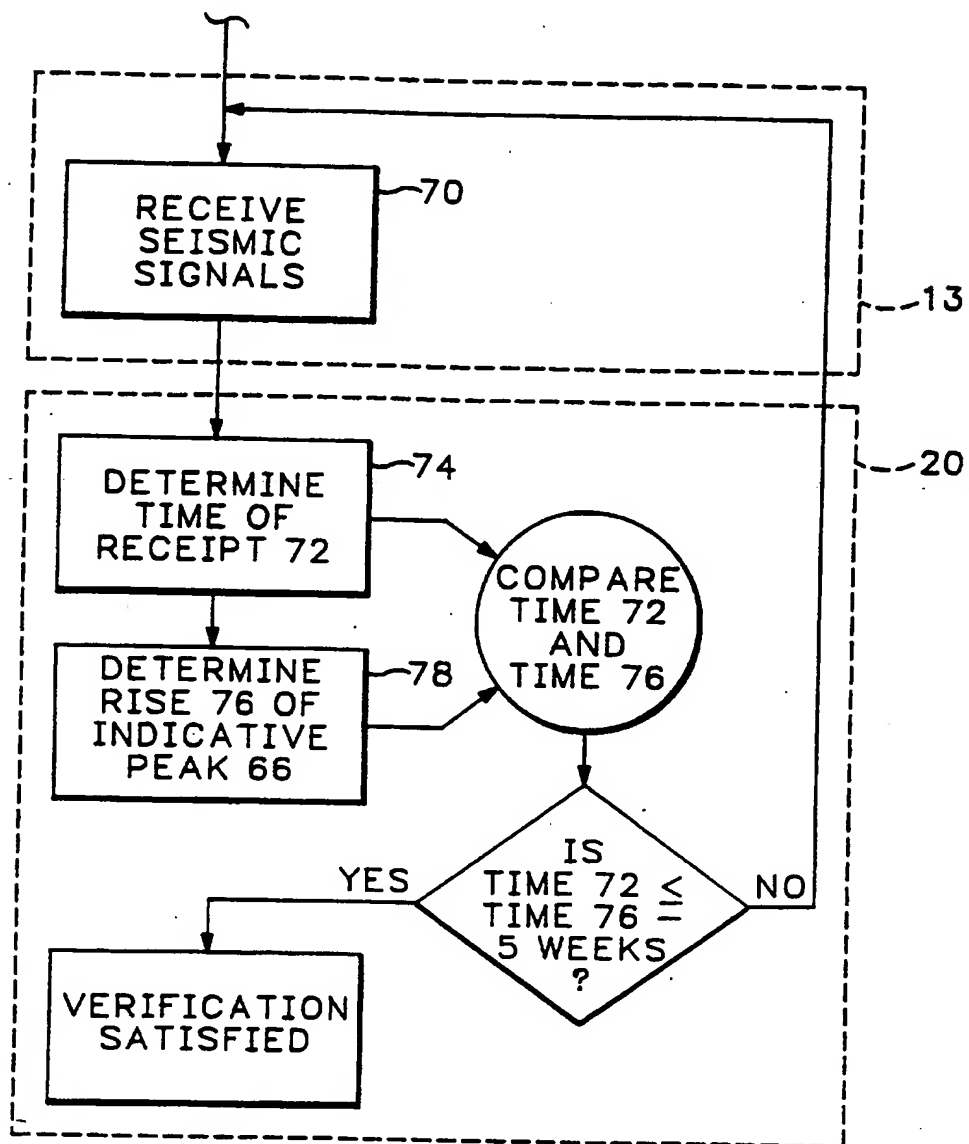


Fig.6

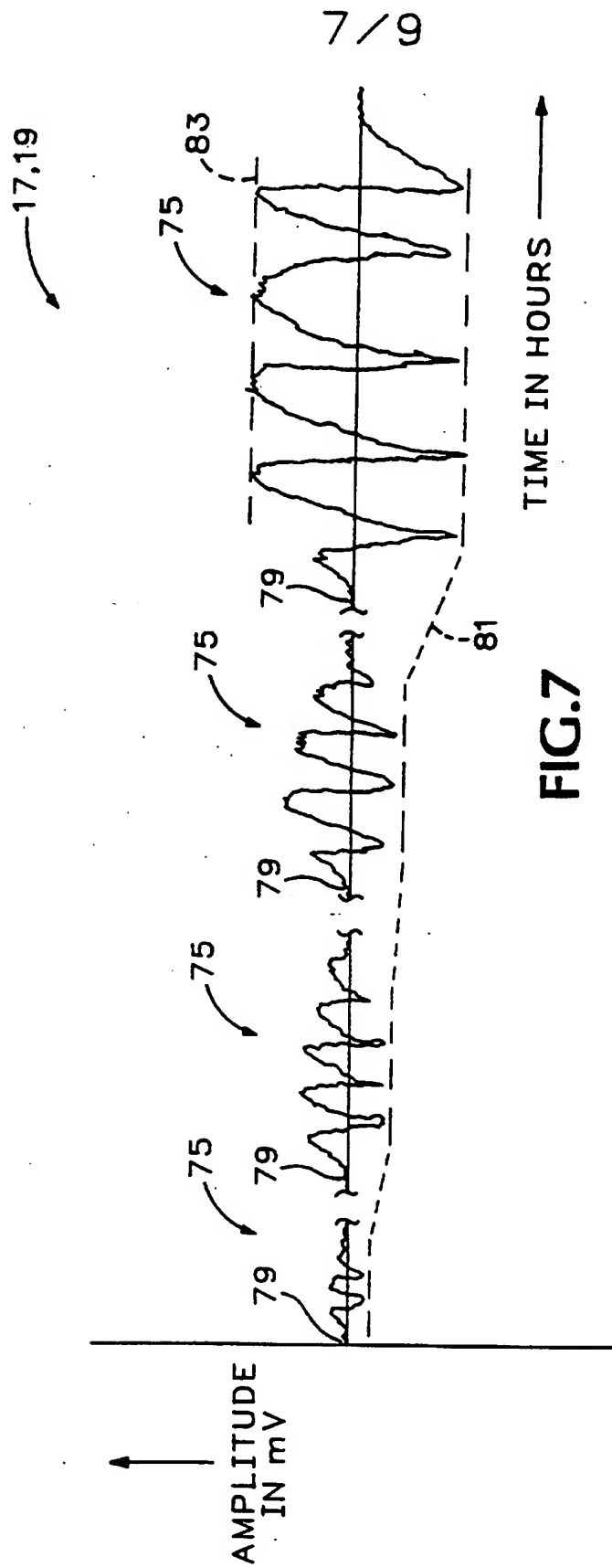


FIG.7

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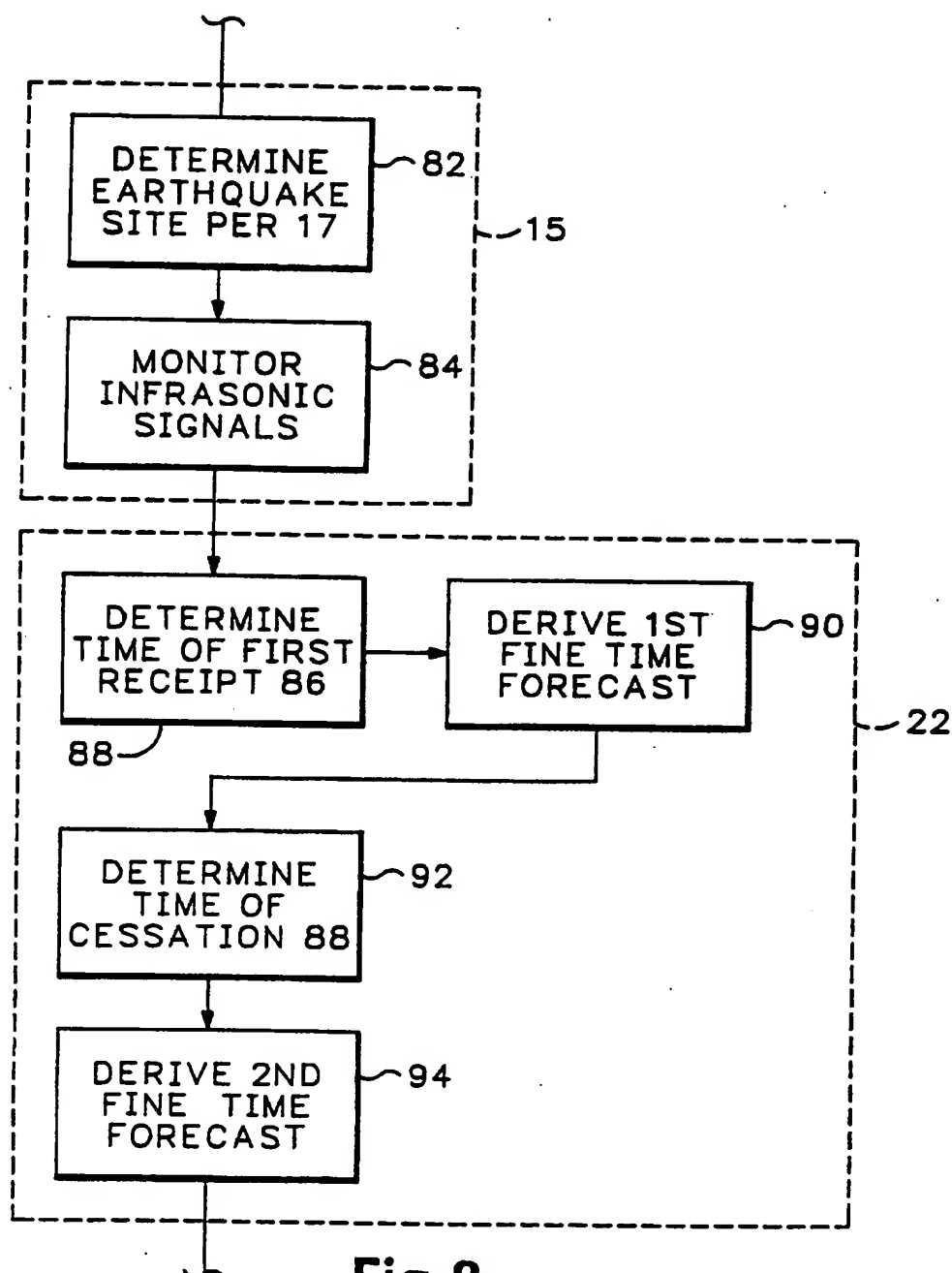


Fig. 8

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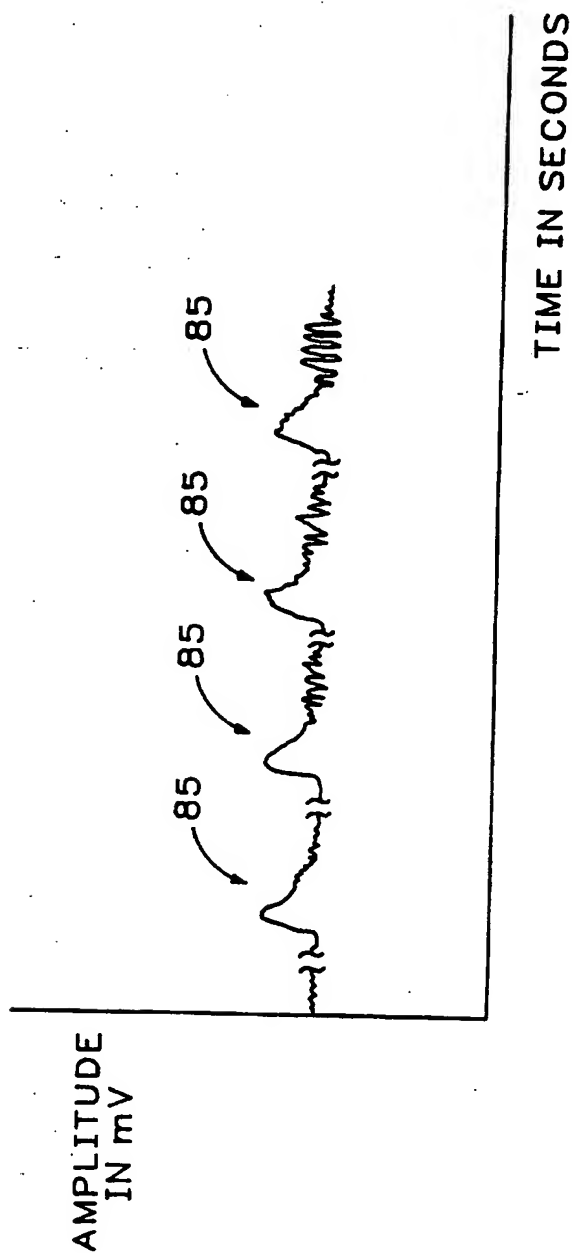


Fig.9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/14052

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : G01V 3/08

US CL. : 364/420; 324/344,348,350

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 364/420; 324/344,348,350

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

search terms: earthquake(s) (p) (forecast(ing) or prediction, ing, s))

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,612,506 (VAROTSOS ET AL.) 16 September 1986, col.1 &2	1-31
X,P	US, A, 5,387,869 (ENOMOTO) 07 February 1995 see Figs. 5A & 5B.	1-3, 7-9, 12, 13, 15, 17, 21, 25, 28, 30 and 31.
Y	US, A, 5,148,110 (HELMS) 15 September 1992, abstract.	3, 30
A	US, A, 4,884,030 (NAVILLE ET AL.) 28 November 1989, abstract.	1-31
Y	US, A, 4,904,943 (TAKAHASHI) 27 February 1990, see col. 5	1-31

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search

14 FEBRUARY 1995

Date of mailing of the international search report

09 MAY 1995

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INTERNATIONAL SEARCH REPORTInternational application No.
PCT/US94/14052**C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,187,331 (SAKATA) 16 February 1993, abstract.	1-31
Y	US, A, 4,724,390 (RAUSCHER ET AL.) 09 February 1988, abstract	1-14, 25
Y	US, A, 4,837,582 (TAKAHASHI ET AL.) 06 June 1989, abstract.	1-31
Y	US, A, 5,256,974 (PADDEN) 26 October 1993, cols. 3 and 4	17-31

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